THE M8.7 NIAS EARTHQUAKE OF MARCH 28, 2005
IN
NIAS ISLAND, INDONESIA

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1 PURPOSE, MEMBERS AND ITINERARY

Japan Society of Civil Engineers decided to dispatch a team of experts and engineers to Nias Island to support and to provide to provide expertise advices and technical assistance to the re-construction and restoration of infra-structures and to improve the seismic resistance of existing buildings with retrofitting from April 24 till 27. The team inspect all infrastructures and buildings through land-surveying.

The team consists of the members from Universities and engineers from construction companies directly involved on earthquake engineering members under the general coordination of Prof. Dr. M. Hamada from Waseda University and Chairman of Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers:

- Prof. Dr. Ö. Aydan, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
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The itinerary of the support team during inspection of infrastructures and buildings is as follows (Figure 1.1):

April 24, 2005: To inspect roadways and bridges and buildings between Gunung Sitoli and Lahewa (accessible as far as Muzoi River), tsunami traces

April 25, 2005: To inspect roadways and bridges, slopes and buildings between Gunung Sitoli and Sorake Beach (Telukdalam), port facilities at Telukdalam, tsunami traces,

April 26, 2005: To continue to inspect roadways and bridges, slopes and buildings between Sorake Beach (Telukdalam) and Gunung Sitoli, traditional houses at villages, Orahili in Telukdalam region

April 27, 2005: To inspect buildings in Gunung Sitoli and port facilities, presentation to local authorities and engineers at the Gunung Sitoli headquarters of Department of Public Works

April 28, 2005: To inspect buildings, roadways, bridges and slopes along the route between Gunung Sitoli and Lawa. Flying from Binanka Airport in Nias Island to Medan. Meeting, presentation of inspection results and recommendations to Vice-Governor of North Sumetra and involved authorities, including Mr Youpi, Parlement deputy for Nias and discussions

April 29, 2005: Luncheon at Consulate General in Medan with Consular General H. Hashi and Consul H. Orikasa and presentation of inspection results and recommendations including 2004 Aceh Earthquake & Tsunami

Figure 1.1 Inspection routes and locations in Nias Island

Figure 1.2 Some views during the itinerary of the support team

2 LOCATION OF EARTHQUAKE

An earthquake with a magnitude of 8.7 occurred on March 28, 2005 nearby Nias Island and Sumatra Island (Figure 2.1). Although the epicenter located by USGS was just beneath Banyak Island, the heaviest damage was observed in Nias Island. The epicenter location determine by HARVARD University was much more close to Nias Island which seems to be consistent with the macro-epicenter. This earthquake is somewhat suprising as it occurred in the region which was assumed to had been partly ruptured in 1861.

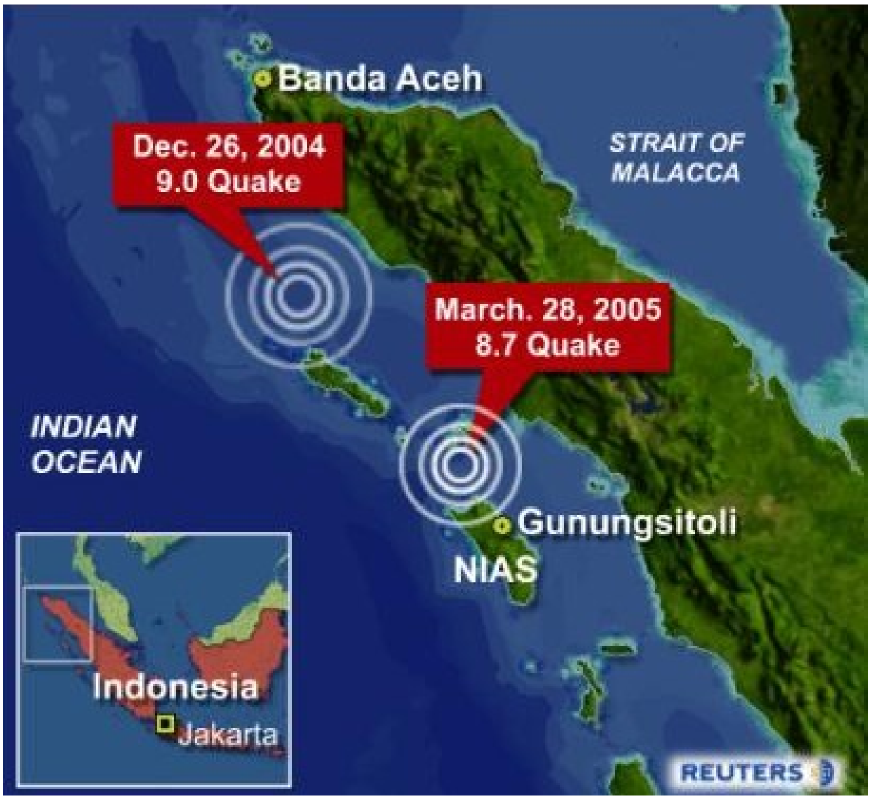

Figure 2.1: The location of the earthquake and major towns in Nias Island

3 TECTONICS OF THE REGION

USGS released a modified map on the tectonics future of the earthquake region as shown in Figure 3.1. The Indo-Australian plate obliquely subducts beneath Euro-Asian plate along the Sunda subduction zone. The earthquakes in this region is mainly due to thrust faulting with a slight dextral sense of slip (Figure 3.2). The earthquake occurred at the Sunda subduction zone in the region, which may be viewed as a region consisting an unruptured part in the 2004 earthquake and a ruptured part in the 1861 earthquake with a magnitude of 8.5. Therefore, the region constitutes a seismic gap and this gap was broken soon after the 2004 event. If the regions ruptured in 1861 and 1833 are correctly depicted, it seems that there is an additional seismic gap in the vicinity of Mentawai Islands. However, this region experienced an earthquake with a magnitude of 7.7 in 1935. Nevertheless, if any earthquake occurs to the south of this region, that seismic gap should be the potential area for a future earthquake nearby Sumatra Island.

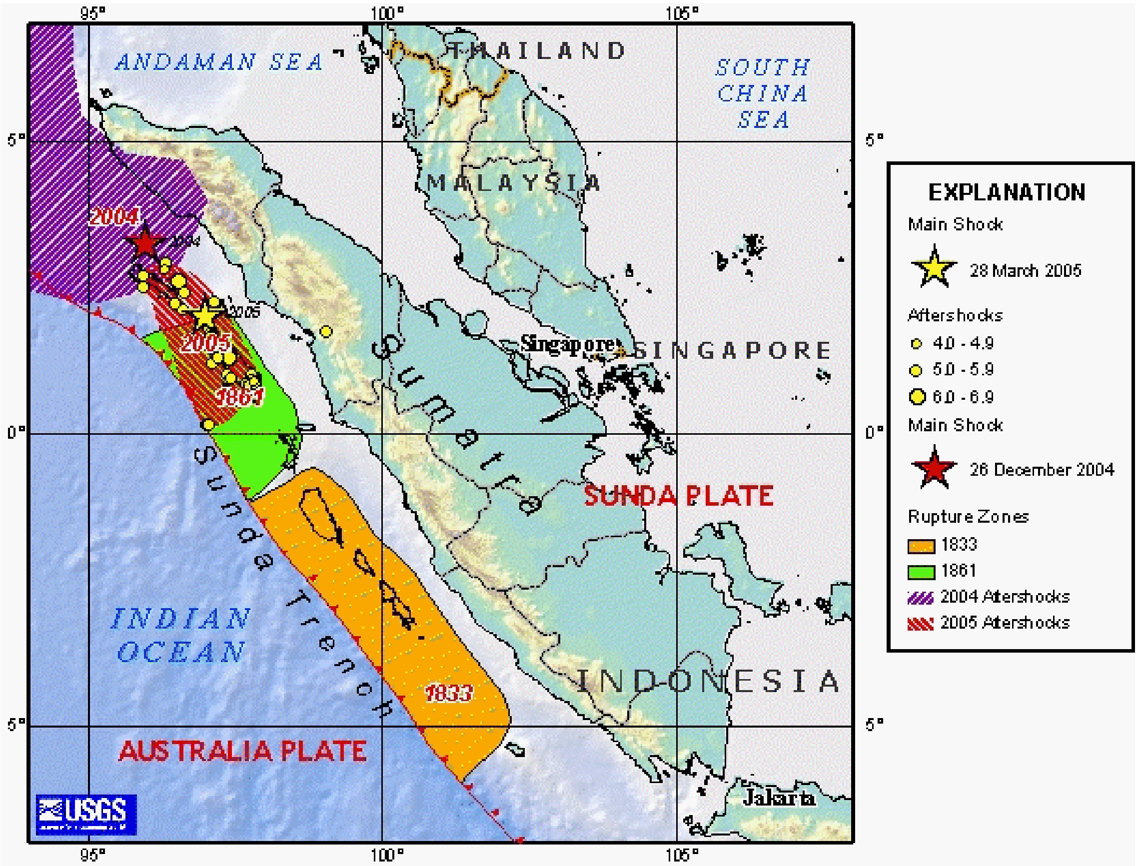

Figure 3.1 Tectonics of the earthquake region and ruptured zones by the previous earthquakes (USGS)

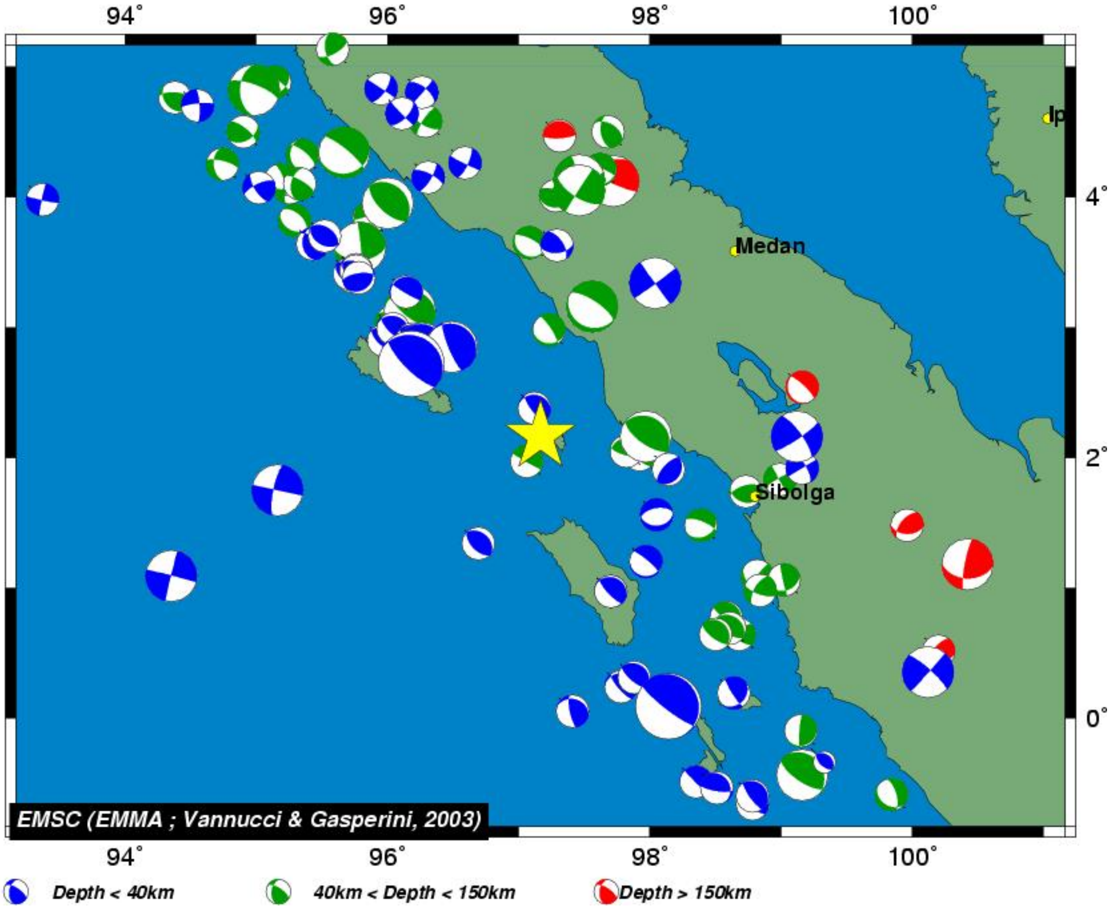

Figure 3.2 Faulting mechanisms in the earthquake region (from EMSC, epicenter by USGS)

4 SEISMICITY

The regional seismicity of a region bounded by Latitudes 0 & 5N and Longitudes 95-100E is shown in Figure 4.1(a) using the catalog of NEIC for a period between 1973 and April 3, 2005. The seismicity projected onto a cross-section along the line A-A' is also shown in Figure 4.1(b). It is easily noted that the seismic activity is low compared to other regions. The region seems to be a seismic gap. The post seismicity is particularly concentrated on the west coast of Nias Island. If the fault plane is extrapolated to the west, the fault breaks should appear on the west side of Nias Island. If the sea-bed obsevations could be done, the fault breaks may be observed at a distance of about 10-20km from the west coast of the Island. However, it would be desirable to re-locate the hypocenters as their depth determined by USGS seems to be based on a default assignement approach.

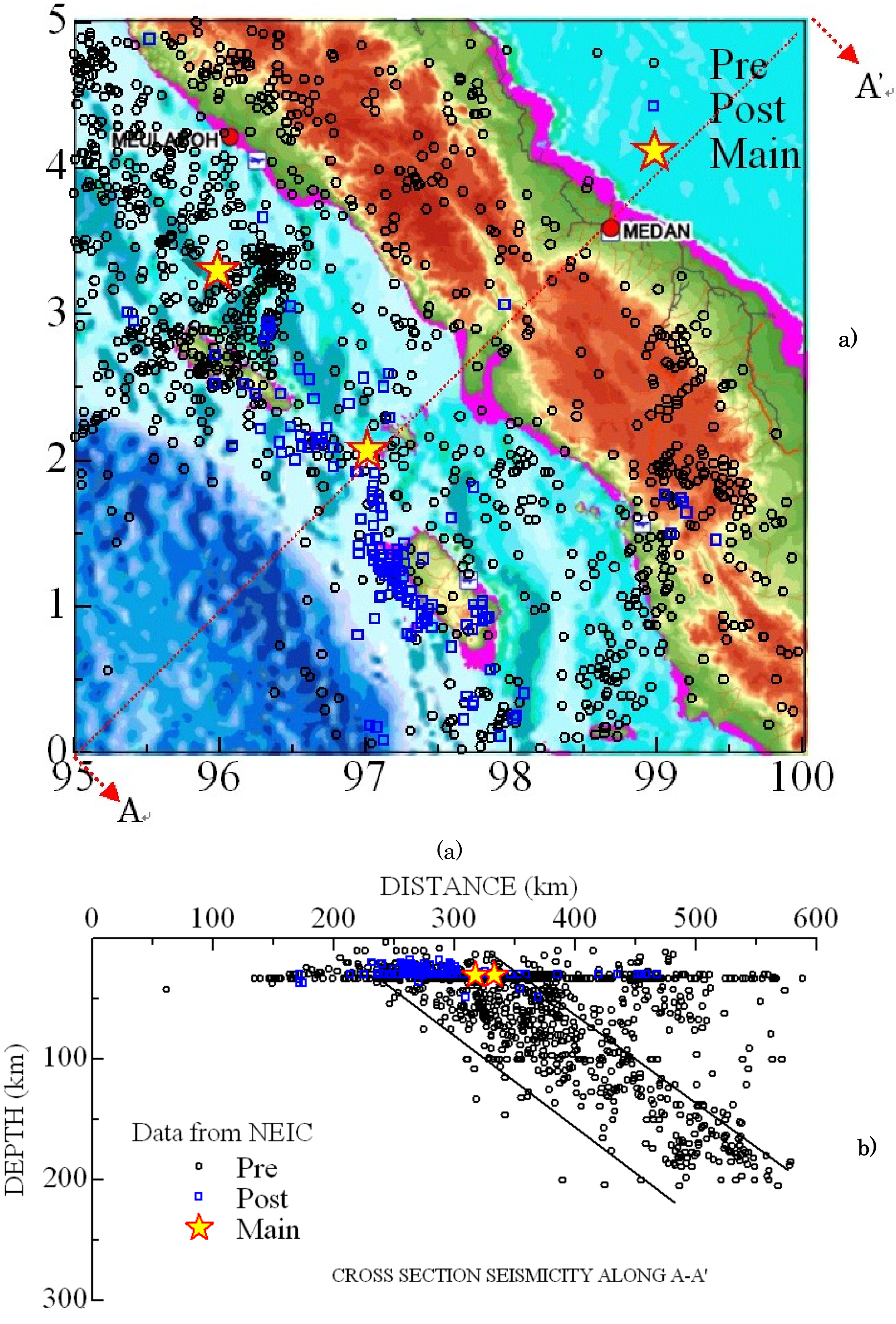

Figure 4.1 Pre-post seismicity of Nias and its close vicinity

5 CHARACTERISTICS OF THE EARTHQUAKE AND FAULTING MECHANISM

The initial estimation of the magnitude (Mw) of the earthquake by USGS was 8.1 and it was revised to 8.7. HARVARD estimated that the moment magnitude (Mw) of the earthquake as 8.6 (Table 5.1). The epicenters determined by USGS and HARVARD differ from each other. While USGS estimated the hypocenter just beneath Banyak Island, HARVARD's epicenter was further SW and nearby Nias Island. Since the damage was much heavier in Nias Island, it seems that the estimation by HARVARD is much close to the actual epicenter. The faulting mechanism of the earthquake estimated by two institutes. The dominant faulting mechanism was inferred to be thrust-type by HARVARD, while USGS inferred the dominant faulting mechanism to be sinistral strike-slip (Figure 5.1). However, the fault plane is very gently inclined and its inclination ranges between 4-7. Yagi of BRI inferred the slip propagation on the hanging wall of the fault as shown in Figure 5.2. The relative slip at the hypocenter is about 10m. The projection of the fault plane and rupture propagation by Yagi (2005) is shown in Figure 5.3. These results indicate that the propagation proceeded towards Nias Island. Yagi (2005) estimated the vertical displacement as 2.4m on the ground surface. On the other hand, Aydan estimated the vertical average displacement of the sea bed to be about 0.7m together with use of the fault inclination data of HARVARD and his empirical relations (Aydan, 1997, Aydan et al. 2002)).

If this earthquake is regarded as an independent event, the aftershock activity should decay with some events having magnitude greater than 6. For this purpose, some statistical analyses could be usefull. Figures 5.4 & 5.5 show some statistical evaluation of aftershocks by EMSC. The aftershock data plotted for 2004 event may be a guiding idea for the expected aftershock activity for the event of March 28, 2005 (Figure 5.6).

Table 5.1 Main characteristics of the earthquake inferred by various Institutes

Institute	M	Mw	LAT (N)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake
USGS	8.7	8.1	2.09	97.016	21.0	251/4/29	132/88/93
HARVARD		8.6	1.64	96.980	24.9	329/7/109	130/83/88

Table 5.2 Rupture and slip characteristics of the earthquake fault

Reference	Magnitude	Length(km)	Slip(m)	Area(km^2)
Yagi (BRI)	8.7	470	10.0	470x100
EMSC	8.6	500		
Aydan	8.3(Ms)	583	5.83	583x40

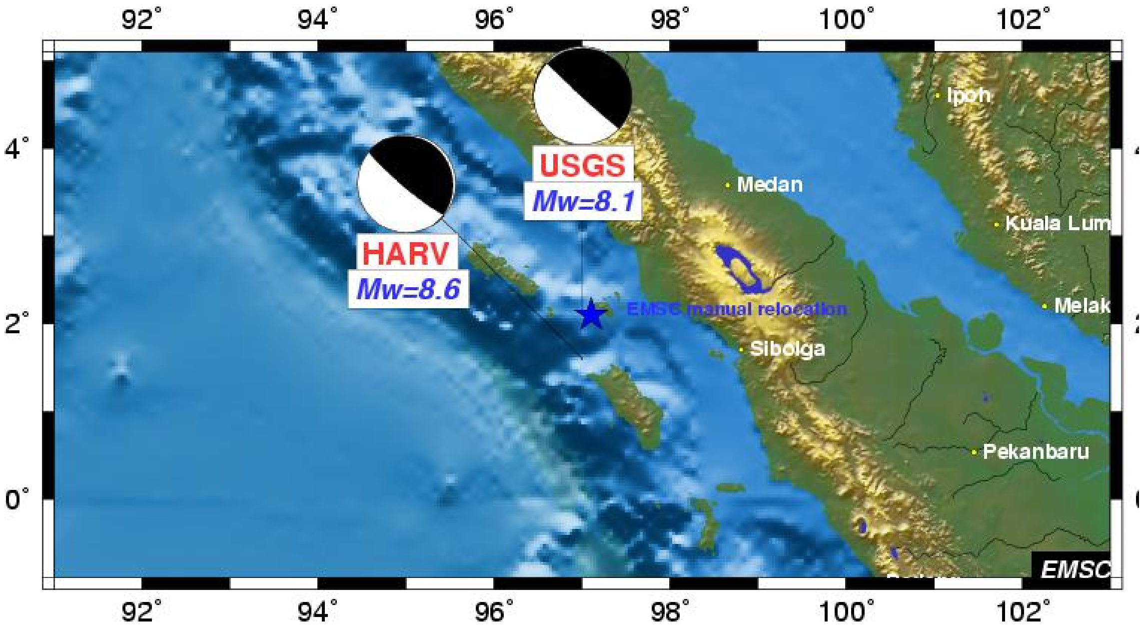

Figure 5.1 Faulting mechanisms inferred by USGS and HARVARD (EMSC)

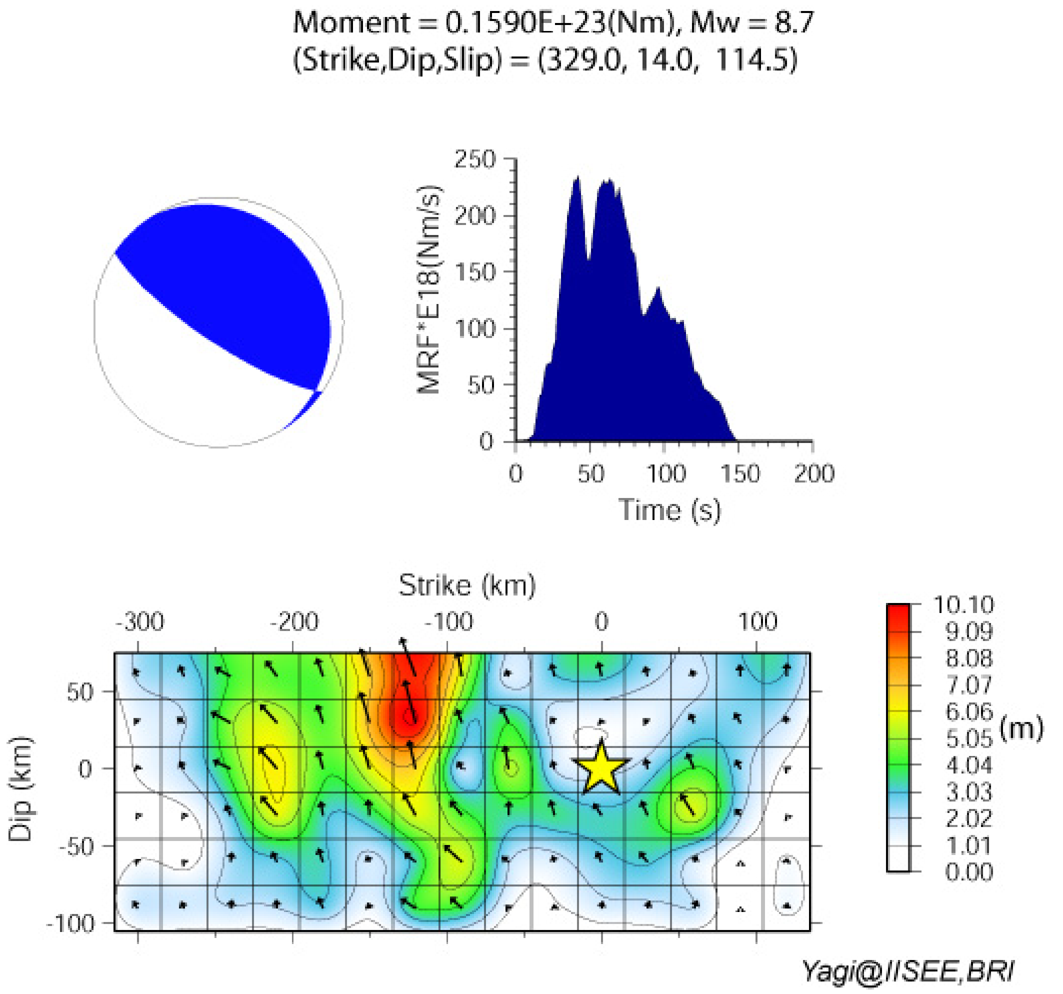

Figure 5.2 Rupture propagation on the hanging wall of the causative fault (Yagi, 2005)

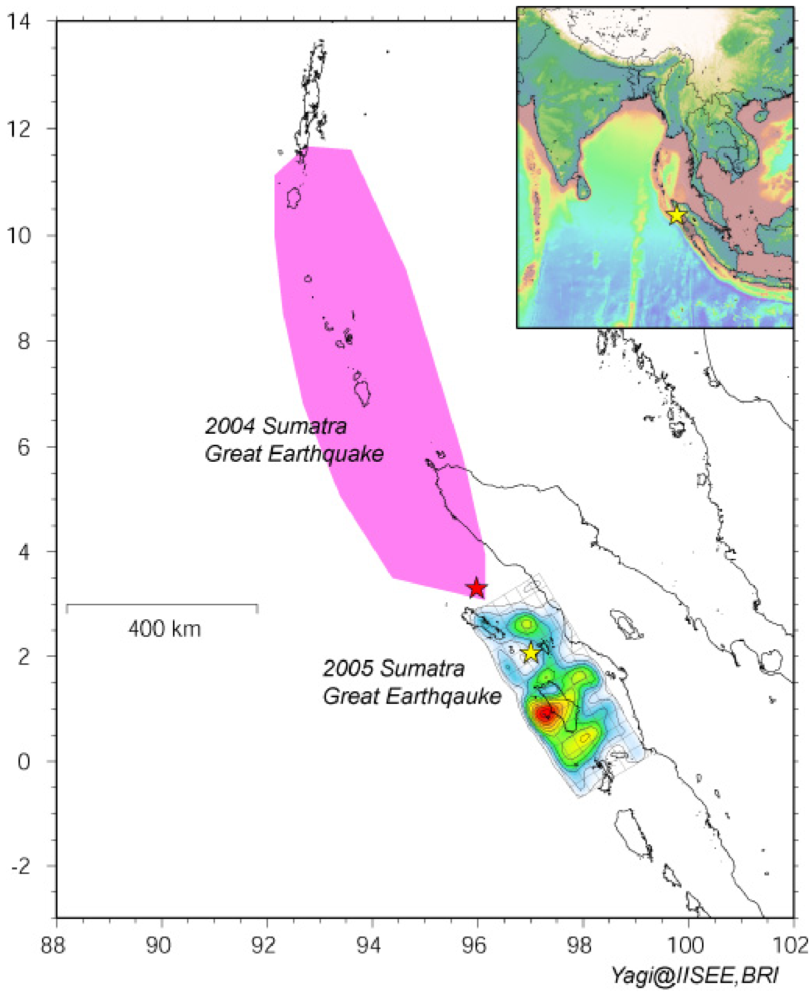

Figure 5.3 Rupture propagation of the causative fault projected on the map (Yagi, 2005)

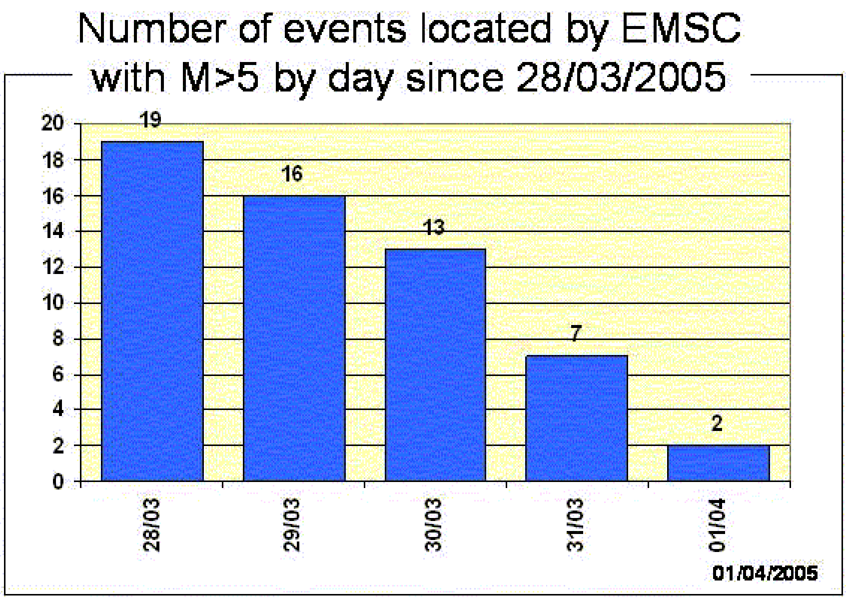

Figure 5.4 Variation of the number of aftershocks with a magnitude greater than 5

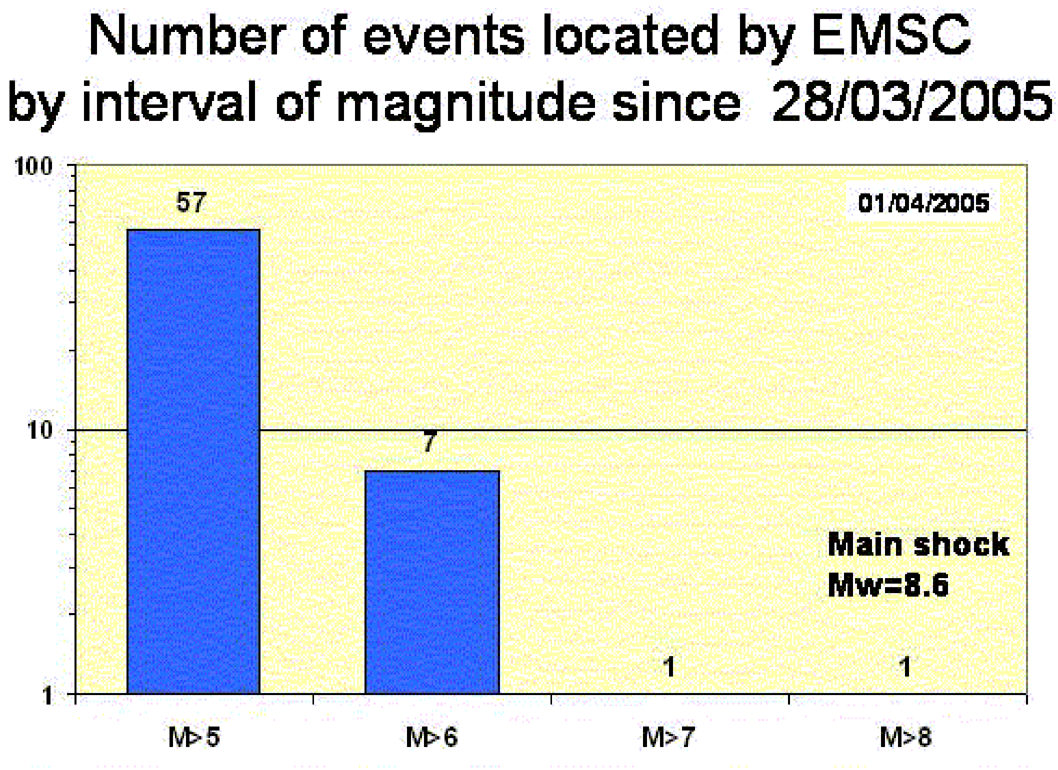

Figure 5.5 Variation of the number of aftershocks with different magnitudes

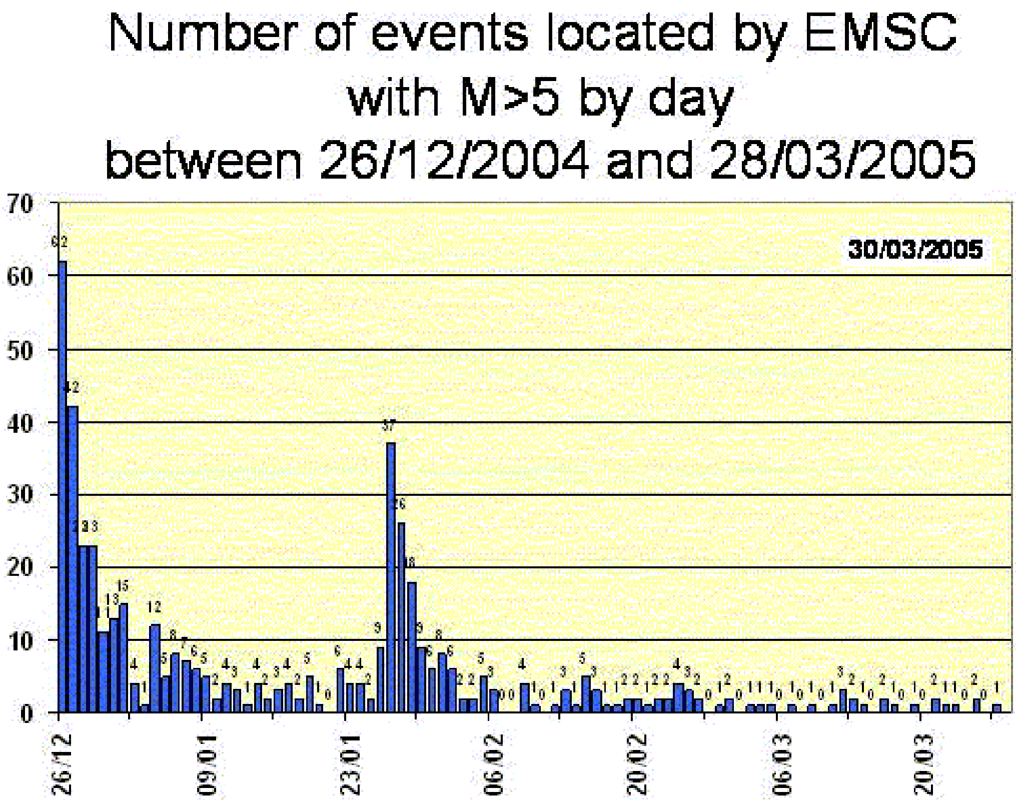

Figure 5.6 Aftershocks activity for the 2004 event (EMSC)

6 TSUNAMI

Tsunami warnings were immediately issued by Pacific Tsunami Warning Center and Japan Metereological Agency to the countries concerned following the earthquake. This quick response was highly appreciated all over the world after the sad experience of the 2004 event.

The travel time and wave height of the tsunami induced by the 2005 event were estimated by Bureau of Metereology of Australia and Institute of Geological and Nuclear Sciences of New Zealand as shown in Figure 6.1 and 6.2. The wave height of the tsunami was more than 3m.

However, the actual scale of the tsunami induced by this earthquake was quite small. According to the chief of Aceh Military Command and observations of local people, the areas hit by the tsunami are Simeulue district, Singkil district, and Pulau Banyak sub-district (Figure 6.3). The wave height was 3-4 meters in Simeulue island. The wharf in the island's main port was said to be badly damaged and that the waves had also affected the island's airport in the coastal town of Sinabang.

Indonesian Meteorological Agency has some tide gauges along the west coast of Sumatra Island. The highest wave was recorded at Sibolga tide gauge and it was more than 1m (Figure 6.4).

According to the Pacific Tsunami Warning Centre (PTWC) tide gauges in the Indian Ocean recorded minor wave activity in the Australian Cocos Island (10-23cm), the Maldives (15cm) and Sri Lanka (25-30cm) (Figure 15). There were also reports of the recession of the sea from Chennai, Mamallapuran, Ramanathapuram district and Tuticorin district in Tamil Nadu and at Machilipatnam in Andhra Pradesh in India.

The effects of tsunami was observed at Telukdalam and Thuemberua districts (Figure 6.6). The tsunami height could be about 4-5m in Thuemberua district while this value is less than 2m in Telukdalam district. The effects of tsunami was said to be observed in western coast of the island rather than the east coast.

Singkil residents have also reported that tsunami hit the coastal area and it is up to 4 meters high (Figure 6.6). A 2-metre wave struck the village of Sirombu on the west coast of Nias. Flooding up to a meter was also reported from as far north as Meulaboh.

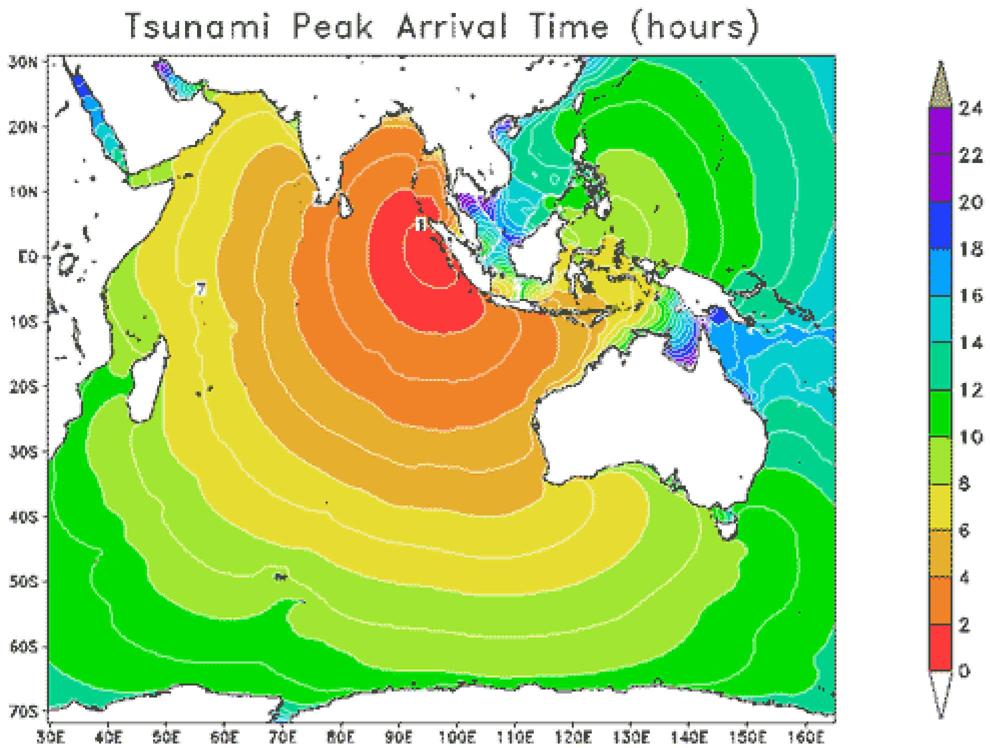

Figure 6.1 Travel time estimated by Bureou of Meteorology of Australia

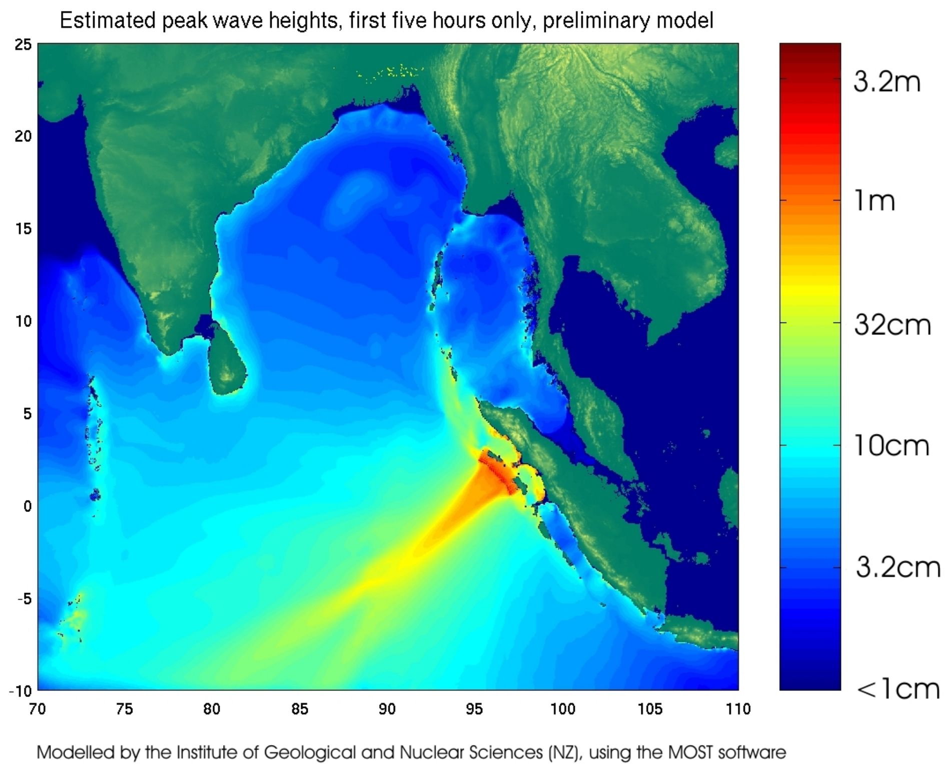

Figure 6.2 Wave height estimated by Institute of Geological & Nuclear Sciences (NZ)

Figure 6.3 Location of towns affected by the earthquake and induced tsunami

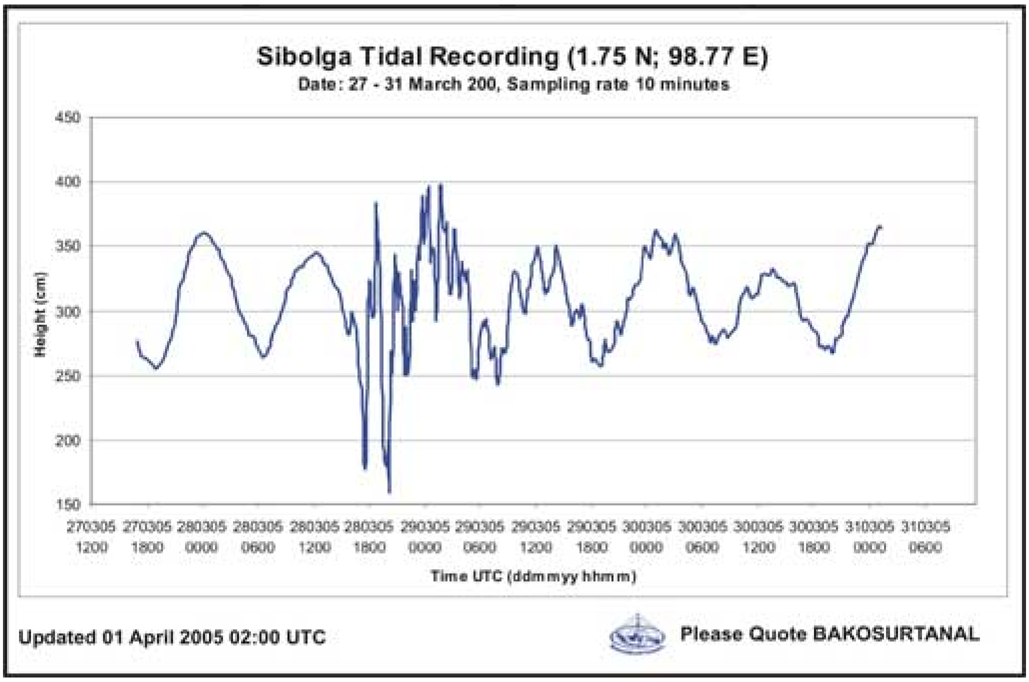

Figure 6.4 Tide gauge record at Sibolga station (from BAKOSURTANAL)

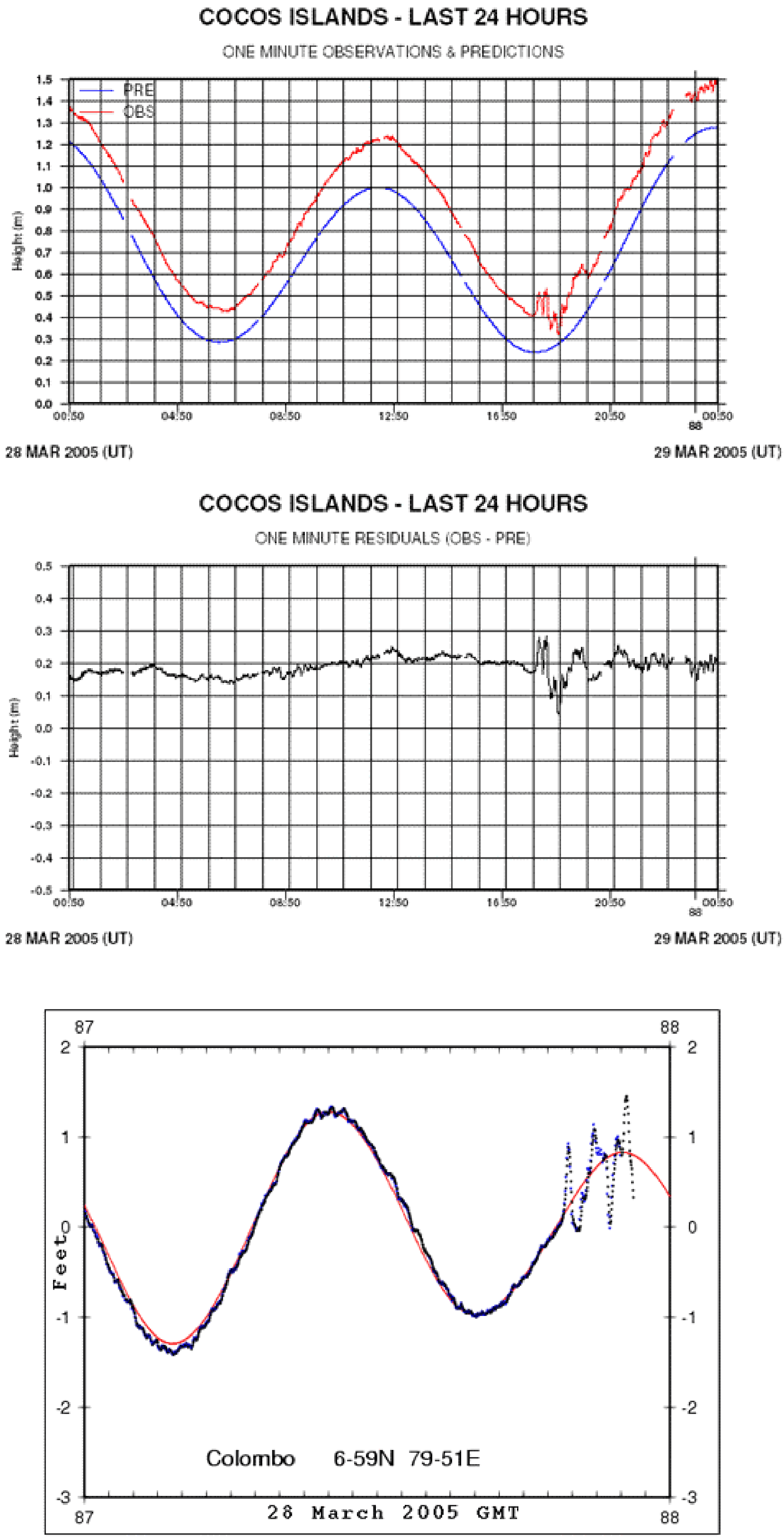

Figure 6.5 Tide gauge records at Cocos (Austalia) and Colombo (Srilanka) (ITIC)

Figure 6.6 Traces of tsunami in Nias and Sumatra Islands

7 STRONG MOTIONS

There is no acceleration record in any of Simeulue, Nias and Banyak Islands and the west coast of Sumatra Island. Therefore, it is almost impossible to know the exact ground motions during this earthquake. The only way is to infer the strong motions from the collapsed or heavily damaged structures such as reinforced concrete buildings, masonry or wooden houses and walls. The authors inferred the MKS intensity as IX from the observations of the collapsed buildings. Furthermore, the maximum ground accelerations should be ranging between 300 and 900 gals depending upon ground conditions using the approach proposed by Aydan (2002) (Figure 7.1).

USGS also conducted a hearing survey on the seismic intensity felt by the people in the earthquake region and neighbouring countries. The seismic intensity was also assigned as IX on MKS intensity scale in Gunung Sitoli in Nias Island (Figure 7.2).

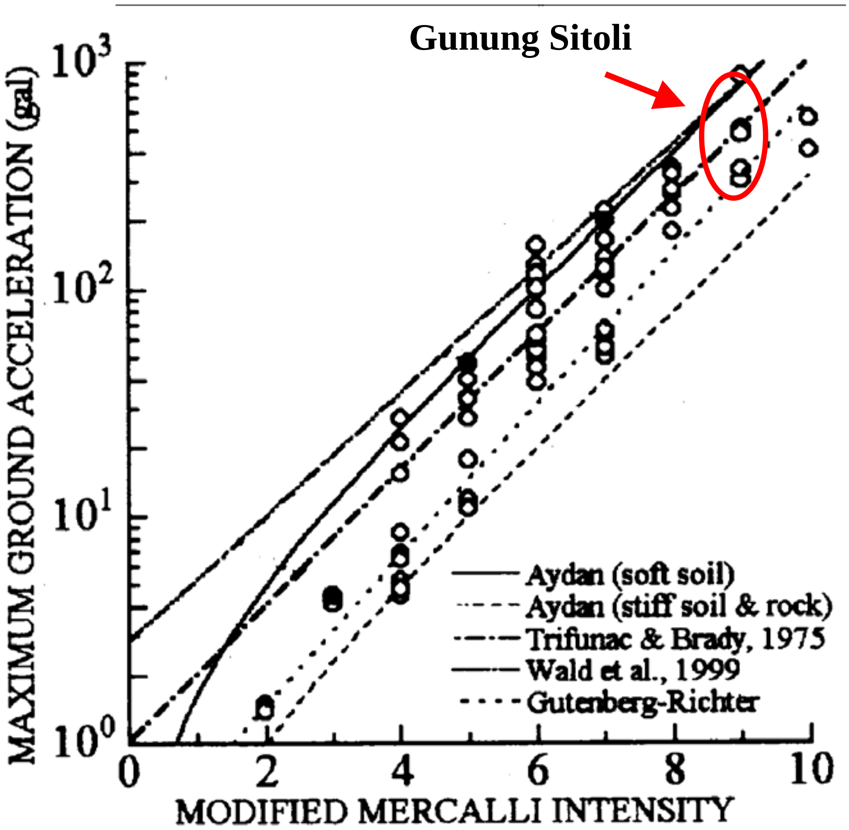

Figure 7.1 Inferred maximum ground acceleration (Amax)

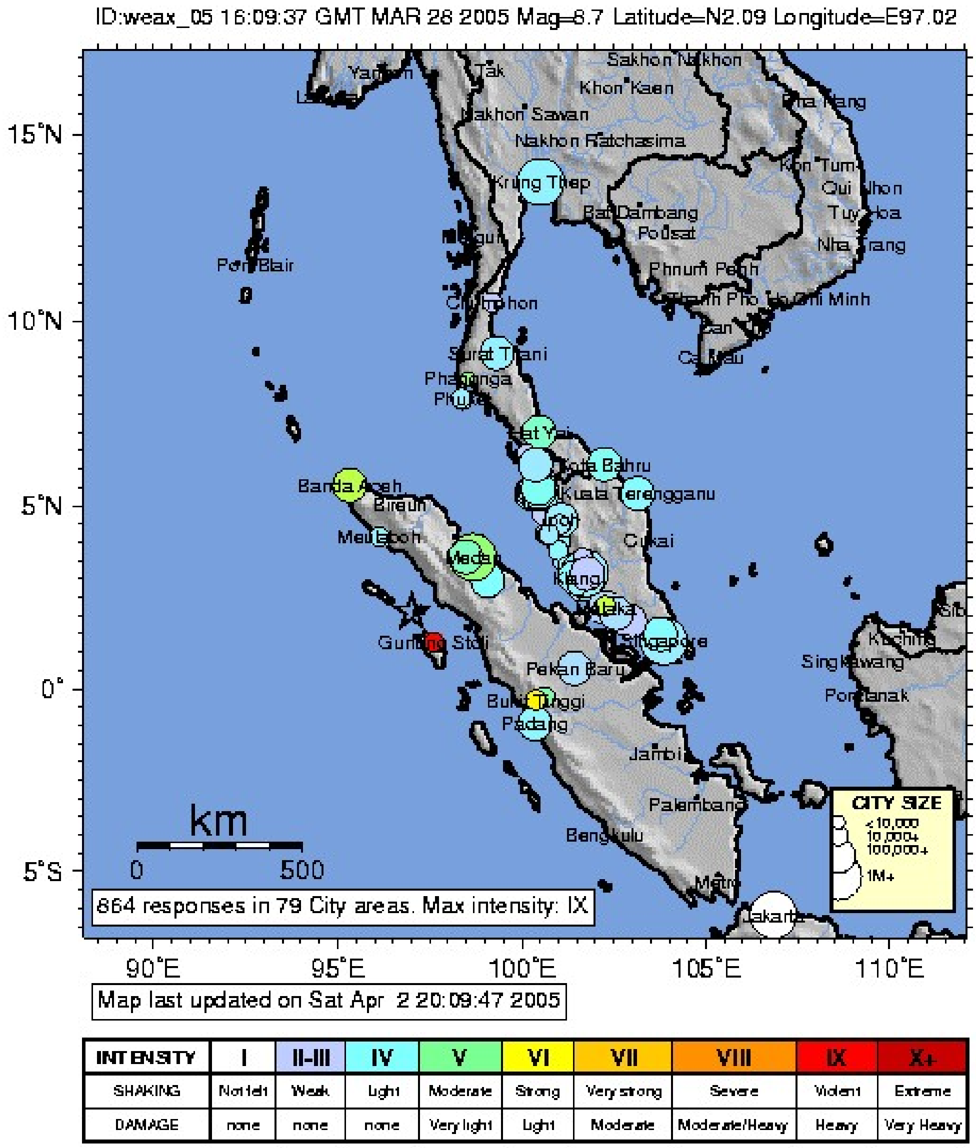

Figure 7.2 Inferred seismic intensity by USGS

8 CASUALTIES

The exact number of casualties and injured people is not well-known. They change depending upon the Indonesian records and UN records (Table 8.1). Anyhow, the town of Gunung Sitoli on Nias Island is severly hit by this earthquake. The casulaties and injuries were mainly caused by the collapse of RC buildings and brick and wooden houses.

Table 8.1 Casualties and injured in the earthquake affected Islands (UN-April 22, 2005)

Island or Town	Casualty	Injured	Population
Nias	847	6279	697,592
Simeulue	100	40	77,751
Banyak			5000

9 DAMAGE TO BUILDINGS

9.1 Damage to Reinforced Concrete (RC) Buildings

The reinforced concrete structures are framed structures with integrated or non-integrated in-fill walls. The reinforcing bars are generally smooth and infill walls are built with red-burned solid clay bricks using mortar. The floor height in the region ranges between 3 to 4m. The inspections of the reinforced concrete buildings indicated that they are mainly failed in the pancake mode. RC buildings are generally found in large towns and large villages such as Gunung Sitoli, Telukdalam and Tetehosi. The concrete buildings having 2 or more stories were either collapsed or heavily damaged. The concrete buildings in Simeulue Island were also heavily damaged or collapsed. The collapse of Sinabang hospital, which was a reinforced concrete building, killed 3 people. The collapsed or heavily damaged RC buildings were all located in low-land areas nearby shores and river banks.

There are many churches in Nias Island built as RC framed structures. The towers and main compouns of churches were all completely collapsed or heavily damaged and the causes of damage or collapses of churches were exactly the same as RC buildings. In addition, the heavy damage to churches situated in hills was caused by the complete or partial landslides and movements of slopes.

The main causes of the collapse or heavily damage of the structures in this earthquake can be broadly classified as follows:

a. Soil liquefaction and lack of the soil bearing capacity
b. Large ground settlement in the coastal areas and nearby river banks
c. Fragile structural walls and lack of lateral stiffness,
d. Poor concrete quality and workmanship,
e. Plastic hinge development at the beam-column joints,
f. Lack of shear reinforcement and confinement,
g. Soft story,
h. Pounding and torsion and
i. Ground motion characteristics (i.e. multiple shocks, long duration etc.).

The causes (a) and (b) should be generally regarded as site effects and local ground conditions which affected residential apartment buildings in the region. Although it is not known exactly, the 15-20 percent of damaged buildings in the Gunung Sitoli either settled up to 1m or tilted and toppled due to ground liquefaction and associated lateral spreading (Figure 9.1). Due to high level of underground water table and liquefiability of the ground without raft foundations and continuous tie-beams could not resist to ground failures unless they are built on piles extending into the non-liquefiable layer.

Compared to those of December 26 2004 earthquake, so many buildings are affected due to the liquefaction in this earthquake.

Figure 9.1 Liquefaction induced damage to buildings in Adapazarı

The reclaimed area in the coastal region of Gunung Sitoli was strongly affected by the quake. Along the shore of Gunung Sitoli, settlement and lateral spreading of ground occurred. As a result, many buildings in a zone for a distance of about 800m from the shore were partially settled and dilapidated (Figures 9.2). At Fofold along the northern shore of Nias Island, even single story buildings were heavily damaged. The base concrete of these single buildings were fractured into a square-shaped blocks (Figure 9.3). The ground was wavy and sand volcanoes could be observed around the area. Although the trace of sand boiling could not be seen on ground at Telukdalam, many RC buildings along the shore were collapsed or damaged. Similar events also observed along river banks.

Figure 9.2 Effects of liquefaction and lateral spreading on RC buildings

Figure 9.3 Collapsed of heavily damaged single RC story buildings

Fragile structural walls and lack of lateral stiffness were another reasons for the collapse or heavy damage although some groves on the column were constructed in order to increase the integrity of the frame with walls. Although the walls were made of solid red burned clay bricks, they were quite slender (300/10-300/15). These walls were easily come down in the out-of-plane failure mode (Figure 9.4).

Figure 9.4 Out-of-plane failure of infill walls

The poor construction quality and structural design problems should be cited as one of the causes of heavy damage to buildings. Figure 8.5 shows that the spacing of stirrups is too large and their too thin for (a) shear resistance and (b) confinement of concrete. Spacing is generally 200mm or larger for a column even at the column ends and their diameter is 8mm. Furthermore the hoops of stirrups are bent 90-degree instead of required 135-degree bent by the modern seismic design codes. As a result the stirrups become loose following the spalling of concrete cover. The spacing of stirrups at member ends for instance in for a shear wall is more than, 200mm, which is too large for preventing diagonal shear crack formation). Although seismic codes require cross-ties to confine the concrete, they were non-existent in almost all collapsed RC buildings..

Figure 9.5 Thin stirrups with too large spacing and large boulders in a column

Beam-column joints were not designed to transfer shear force and no lateral reinforcement was placed in these joints. As seen in Figure 9.6, the formation of inclined shear cracks near the joint clearly show one of the causes of the heavy damage to RC buildings and illustrate the plastic hinge occurrence at the joint. The ductility provided by the members and the connections was apparently not sufficient to resist such high level reversed cyclic earthquake loadings and imposed large deformations..

Figure 9.6 Typical poorly constructed column-beam joints

Many buildings had shops at their ground floor. Since there are generally no shear-walls to take up the load during earthquakes, the total load is transferred onto the columns. The super structure acts a top-heavy structure on the columns and in-fill walls, which are in poor contact with columns and beams, has no effect against the earthquake loading and they fail subsequently as seen in Figure 9.7.

Figure9.7 Failure of buildings due to soft floor effect

Buildings at the corners of streets collapsed as a result of pounding by the adjacent buildings (Figure 9.8). This is probably one of the important problems in most of town and villages in Nias Island.

Figure 9.8 Collapsed buildings at a corner of street in Gunung Sitoli

The use of non-clean coral sea sand caused the poor adhesion of concrete and the corrosion of steel bars which subsequently reduced the resistance of columns and beams against lateral loads (Figure 9.9). This is a quite serious problem for buildings constructed in town and villages along the shores of Nias Island.

Figure 9.9 Corrosion of steel bars and non-cleaned sand and gravel

The collapses and heavy damage of RC buildings in Telukdalam town, which is about 150km from the epicenter, may be associated with soft ground condition in addition to the problems mentioned above (Figure 9.10). It seems that the ground shaking may be amplified in soft ground as it is the common case for shaking in coastal areas due to earthquakes in inter-plate subduction zones.

Figure 9.10 Heavy damage or collapse of RC buildings in Telukdalam

9.2 Wooden houses

Wooden houses may be divided into modern and traditional types. Many wooden houses are elevated from ground. Although wooden houses generally performed well during earthquake, the damage or collapse of the wooden houses were mainly caused by the dilation of super structure caused by the settlement and lateral spreading of ground liquefaction and landslides (Figure 9.11).

Traditional houses are built with good material and good workmanship, and the damage to this type houses are almost nill except those induced by partial landslide and permanent movement of slopes. The superstructure utilizes good quality cylindrical wooden beams together with truss-type construction method. The villages having traditional houses are all located on hills, where ground motions may be amplified due to topographical effect. When the houses were very close slope crest, some ground cracks with a separation of 100mm and 60mm settlement caused the dilation of super-structure (Figure 9.12). Since these buildings accomodate some relative displacement, the damage was generally non-noticable in the super-structure.

Figure 9.11 Damage to wooden houses and schools

Figure 9.12 A traditional Nias house and a crack in ground at its basement

10 DAMAGE TO ROADWAYS AND BRIDGES

10.1 Roadways

Roadways are generally narrow (less than 5m) and the asphalt surfacing of roadways are generally in poor condition having many potholes. Besides the poor condition of the asphalt surfacing of roadways, the damage was caused by landslides, lateral spreading of liquefied ground, embankment failure (Figure10.1). The cracks on the roadway pavement were either longitudinal or perpendicular or both to the road alignment. Longitudinal cracking was generally associated with lateral dilation of roadway embankment. Perpendicular cracking to the road alignment was generally observed nearby bridge abutments due to lateral spreading of ground. However, such cracking was also observed in areas, which are non-affected either by landslides or lateral spreading. Although the reason is still unknown, a possible explanation may be related to the fracture propagation during faulting.

Figure 10.1 Damage to roads

10.2 Bridges

Bridges in Nias Island may be broadly classified as

- Truss bridges,

- RC bridges,
- RC Box Culvert Bridges,
- Wooden paved steel framed bridges, and
- Wooden bridges.

Long span bridges are either truss bridges or RC bridges with or without box culverts. The list of bridges and dominant forms of their damage are listed in Table A1 and the characteristics of damaged state of bridges are given in Figure A1-A47.

The bridges are designed as simple-supported structures. The bearing supports of many bridges do not have shear-keys or stoppers against both horizontal and vertical movements. The heavily damaged non-accessible large bridges within the surveyed area are Muzoi bridge between Gunung Sitoli and Lahewa route and Sawo bridge between Gunung Sitoli and Telukdalam nearby Tetehosi. These bridges consist of truss super-structures and RC box culverts. The piers of Muzoi bridge were tilted and settled due to bearing capacity and lateral spreading problems associated with liquefaction of ground. The engineers of Department of Public Works pointed out that piers have piles reaching rock formation. It seems that the piles were designed against vertical loads and horizontal loads were not considered. The ground is laterally moved towards the river, which can be clearly inferred from the tilted electric poles next to the bridge and the lateral movement of the ground was more than 4m on both sides.

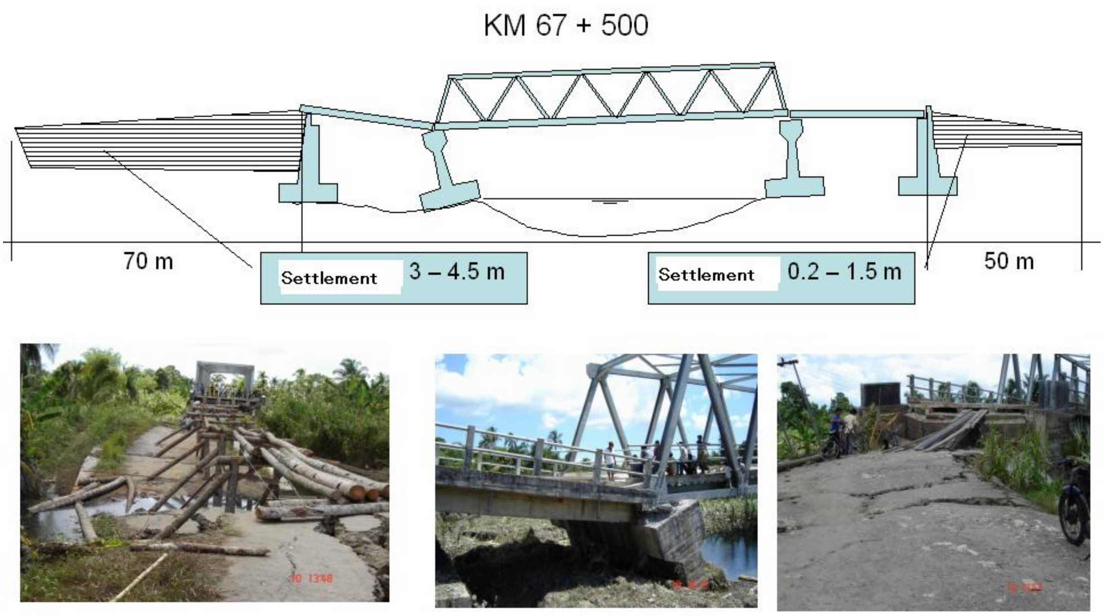

Figure 10.2 A sketch of Muzoi River Bridge and some views of its present state

The second pier of Gawo bridge was tilted and slid towards the upstream side of the river and the box-culvert to this pier was also tilted and slid together with the pier (Figure 10.3). The upper deck of the truss section of the bridge is horizontally shifted about 1.3m. The piers were constructed without using pile foundations. The site investigation indicated that there is a mudstone-like layer and overlaying soil layers consist of sand, gravel and sandy-silt from bottom to top (Figure 10.4(a)). These layers are tilted towards upstream side with an inclination of 5-10 degrees. Furthermore, the river flow is directed towards the pier and box-culvert. Although the construction details of the pier and box culvert are not known, it seems that the toe erosion (scouring) of the pier and box culvert together with liquefaction of inclined sandy layer and horizontal shaking may be the major causes of the damage to Gawo bridge.

Figure 10.3 Gawo Bridge nearby Tetehosi

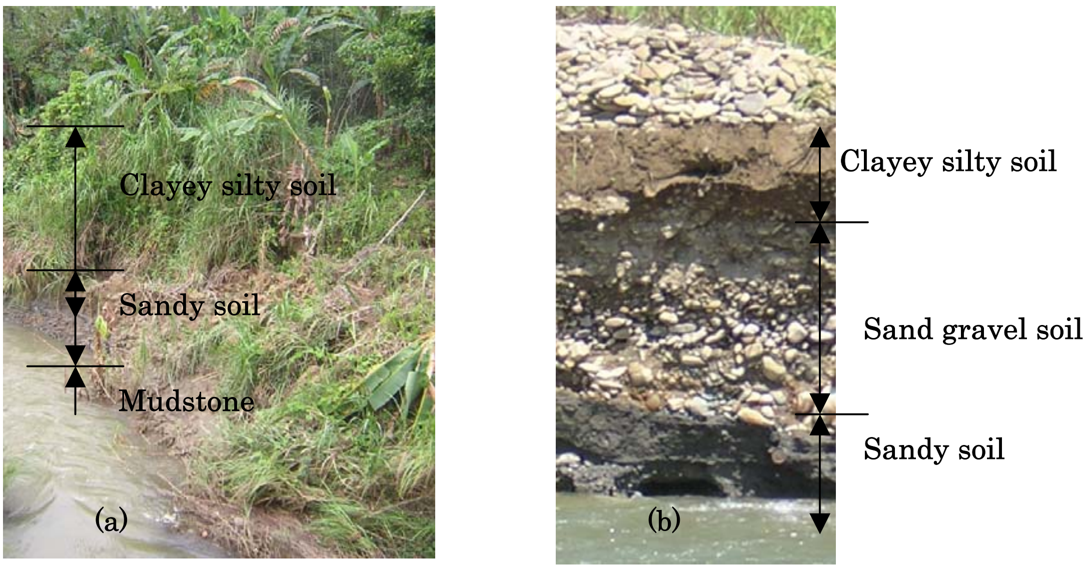

Figure 10.4 Typical Soil Conditions at abutments of bridges

RC bridges in Gunung Sitoli town were damaged by the lateral spreading of liquefied ground. The bridge foundations have some piles and some of these piles were broken at the top (Figure 10.5).

Figure 10.5 Some examples of damage to RC bridges

Many truss bridges along Gunung-Sitoli and Telukdalam route were damaged by permanent movement of abutments as a result of lateral spreading of liquefied ground. The ground consists of mudstone-like layer, sand layer and clayey-silty soil and top organic soil (Figure 10.4(b)). Sandy layer is generally found at the water level of river and it is expected to be full saturated. During earthquake shaking, it seems that this sandy layer is liquefied and caused the lateral spreading of ground. The lateral spreading of ground was particularly amplified on the convex side of the river bank as the ground can freely move towards the river. These movements caused high lateral forces on the abutments, which caused the sliding and tilting of piers or fractured the piles of the abutments of truss bridges. Similar situations are also observed on RC bridges.

Box culvert bridges generally performed well during the earthquake except locations were scouring or ground settlement occurred (Figure 10.6).

Figure 10.6 Non-damaged RC box culvert

The approach embankments of bridges are generally damaged and settled due to lateral spreading of ground and failure of wing-embankment walls. The settlements were generally greater than 30cm in many locations (Figure 10.7). The backfill materials of approach embankments consist of gravelly soil and it is expected that the potential of settlement or liquefaction is low.

Figure 10.7 Settlement of approach embankments of bridges

The damaged bridges generally need to be re-constructed and it should be next to existing piers with necessary geotechnical investigation of ground and its characteristics. The present truss decks can be used in the new-constructions with some replacement of damaged elements and bolts and bearings together with appropriate stopper against horizontal and vertical relative movements.

11 DAMAGE TO PORT FACILITIES AND COASTS

There are some damage to port facilities in Nias Island due to ground shaking rather than tsunami (Figure 11.1). The new wharf of Gunung Sitoli port was damaged by the lateral spreading of liquefied ground. As a result, the pile heads fractured and settled . Furthermore, there was a relative movement of 15cm between the section of the wharf. In Telukdalam new port, a part of wharf sank into the sea and some pile heads were fractured by collision of wharf segments..

(a) Damage at Gunung Sutoli port

(b) Sank part of the wharf at Telukdalam new port

Figure 11.1 Damage to ports in Nias Island

12 SLOPES AND ROCKFALLS

The top rock is porous coral limestone and the joints are widely spaced. Phillite-like rock is beneath the coral limestone. Many rockfall are observed particularly along the roadways pass through porous limestone (Figure 11.1). Slope failures are generaly surfacial failure of weathered loose material or individual rock falls. These rockfalls directly hit the roadways. Furtunately, nobody was killed by these rock slopes and rockfalls. In some places the slope has overhangs the roadway. Therefore, it is necessary to widen and cutting slopes to the slope angle less than 60 degress is desirable with shoulder pockets for individual and limited rock falls.

Figure 12.1 Various slope failures along inspected routes

The permanent movements of slopes consisted of weathered rock is also likely during this earthquake. The inspections of villages with traditional houses such as Ohalili nearby Telukdalam and the routes of Lahusa - Telukdalam and Gunung Sitoli – Lawa village indicated that there were permament movement of slopes. The slope for example between Gunung Sitoli and Lawa village consists of soft sandstone and siltstone. As seen in Figure 12.2, the top part of the slope consists of weathered soft rocks having their bedding plane inclinations largely varied. Figure 12.3 shows some example of slope movements in this type of materials.

Figue 12.2 Intercalated sandstone, siltsone and mudstone (brown part is weathered)

Figure 12.3 Some slope movements and rockfall in weathered soft sedimentary rocks

13 LIQUEFACTION AND LATERAL SPREADING

As expected from the magnitude of this earthquake, the liquefaction of sandy ground is very likely. The sandy ground is observed along sea shore and riverbanks. The traces of ground liquefactions could be observed in various locations along the inspected routes. Figure 13.1 shows some examples of ground liquefaction. The all possible forms of ground movements and the effects of ground liquefaction were observed such as sandboils, lateral ground movements, settlement. The damage induced in Gunung Sitoli is widespread along the coastal area and reclaimed ground and in other coastal towns. The lateral spreading of ground nearby bridge abutments were almost entirely associated with liquefaction of sand soil layer as shown in Figure 10.4. However, the geotechnical investigations of ground are lacking in Nias Island and it would be desirable to carry out such investigations for areas particularly affected by ground liquefaction is necessary.

Figure 13.1 Some examples of sandboils in Gunung Sitoli and coastal areas

14 LIFELINES

Following the earthquake, lifelines such as electricity, water supply and sewage were severly affected by the earthquake. The electric supply in Nias Island is achieved through oil-powered power generators. The supply of electricity is still insufficient and its voltage is very unstable. In liquefied areas, many electricity poles were broken or tilted by the lateral spreading of ground and slope failures (Figure 14.1).

Water supply network is also in bad shape and the water pipes next to bridge abutments were ruptured by the ground movements (Figure 14.2).

The sewage system exist in only towns and villages and sanitary conditions should be improved. As ground liquefaction was widespread, the breakage of sewage pipes are likely to be broken and uplifted in liquefied areas as seen in Figure 14.2. Since the main purpose of the visit of the team to the area was associated with roadways and bridges this time, the inspections on lifelines are only restricted to those observable during the inspections.

Figure 14.1 Effects of the earthquake on electricity system

Figure 14.2 Views of damage to water pipes and sewage

15 RECOMMENDATIONS FOR REHABILITATION AND RECONSTRUCTION

Recommendations for rehabilitation and reconstruction for infrastructures and buildings are presented herein

15.1 Roadways

The recommendations for roadways are as follows:

- The present roadways are too narrow and they should be widened for smooth flow of traffic
- The foundations of roadways must be improved to increase their bearing and water drainage capacities.
- The asphalt surfacing of roadways must be re-done with appropriate thickness

15.2 Bridges

Recommendations for rehabilitation and re-construction of bridges are as follow

- The inspection of bridges should be carried out to the flow chart shown in Figure 15.1
- Almost all bridges should be re-constructed.
- The truss decks of bridges can be used with some replacement of damaged parts
- Truss bridges are much more preferable for the region
- Ground investigations must be done to have fundamental data on ground

characteristics for the structural design of piers and abutments.

- Pile design should be re-considered and their length should be sufficiently long to have required end bearing.
- The foundation pile should be designed to resist to lateral flow force of liquefied ground.
- Reconstructed abutments have wing walls to prevent collapse of approach road to bridge.
- The damaged bridge will be repaired by temporary measures. The displaced abutment should be reconstructed on new alignment since it takes long time to rebuilt (Figures 15.2, 15.3 & 15.4)
- The truss bridges will be inspected in detail and decided whether it is possible to reuse it. Damaged parts will be replaced.
- The concrete bridge will be inspected in detail and damaged bridge will be reconstructed. Even if they have no problem, the bridge may be set back and reconstructed due to condition of the foundation ground and geographical conditions.

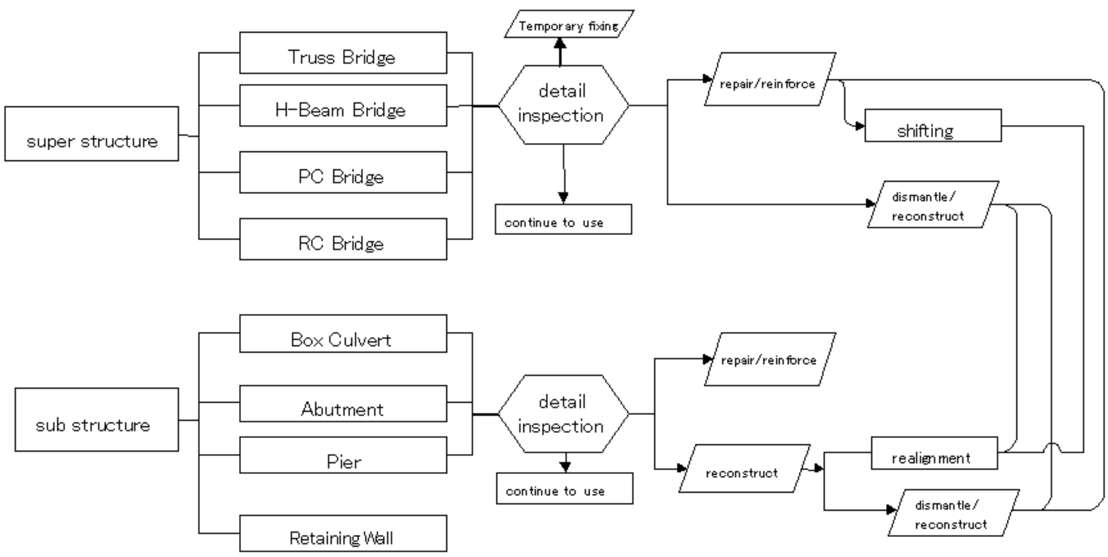

Figure 15.1 Inspection and re-construction procedure for bridges

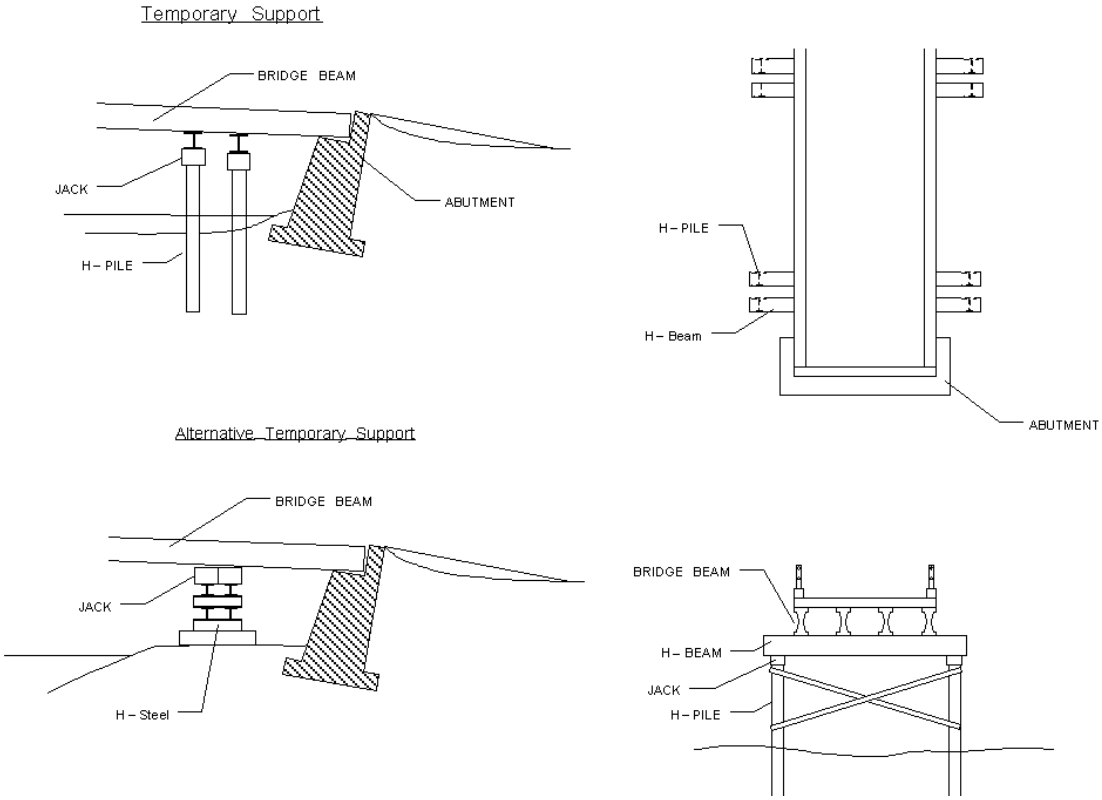

Figure 15.2 Temporary support of damaged abutments

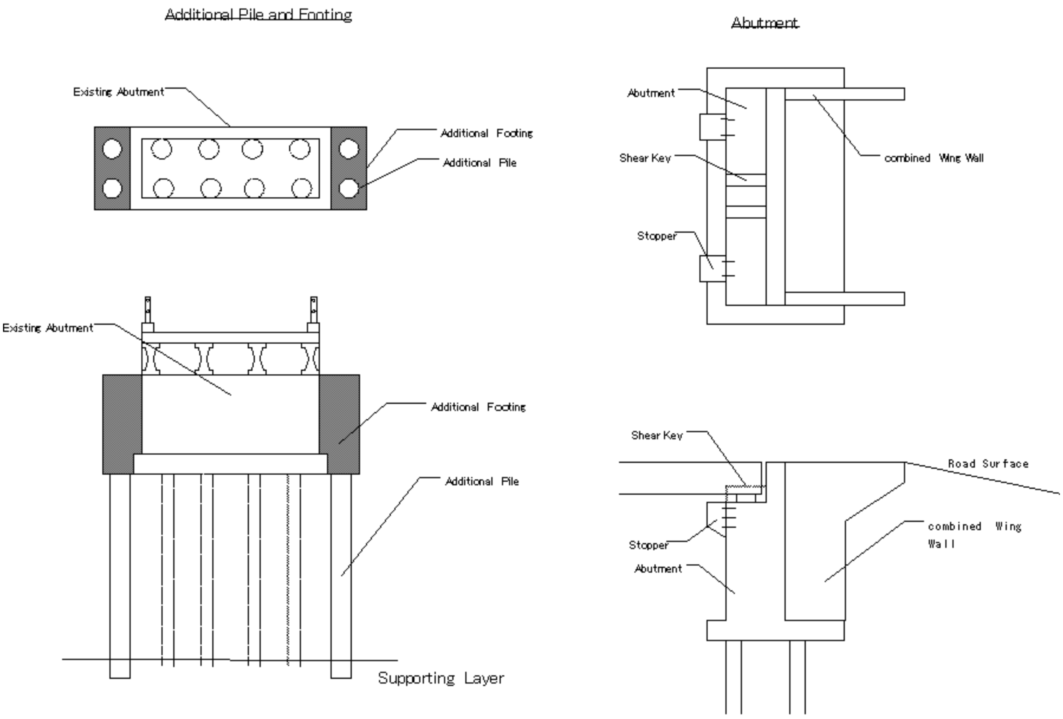

Figure 15.3 Temporary support of damaged abutments

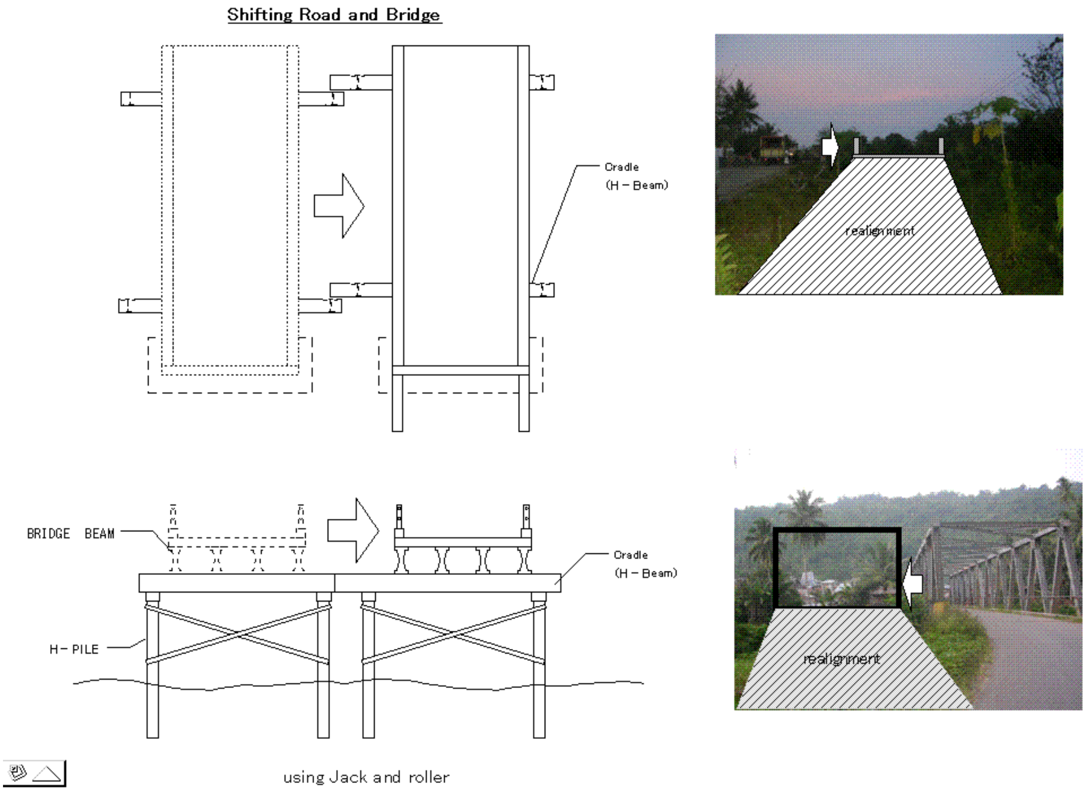

Figure 15.4 Shifting superstructure to new abutments

15.3 Buildings

Recommendations for rehabilitation and re-construction of buildings are as follow

- Present RC buildings do not satisfy the basic requirements of modern seismic design codes for buildings
- The steel bars of reinforcement and stir-ups are too thin to resist lateral forces
- The column beam connections are not properly done and the modern seismic design codes must be strictly implemented with the consideration of country conditions
- The level of workmanship must be improved by education.
- The size of columns should be increased with sufficient reinforcement and the use of shear walls should be encouraged instead of brick walls. If shear-walls could not be utilized due to economic situations, it is desirable to built wall first and then cast concrete column and concrete base slab since the present column-beam connections are very poor.
- The story number in structural design must be obeyed during the implementation as the actual story number is higher than the original story number
- Box-like (mat) foundations should be used for buildings in liquefiable area if piles could not be used

- Seismic characteristics of ground must be measured in towns and villages by provincial authorities
- Tie-beams must be used in the foundation design of buildings

15.4 Slopes

Recommendations for rehabilitation and re-construction of slopes are as follow (Figure 15.5)

- Slope angle should be decreased for increasing its stability
- Pockets must be constructed against rock falls
- Reinforcement by rockbolts and slope protection measures such bolted mesh-wire, gabion walls etc. should be utilized.

Figure 15.5 Slope stability improvement and protection measures

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